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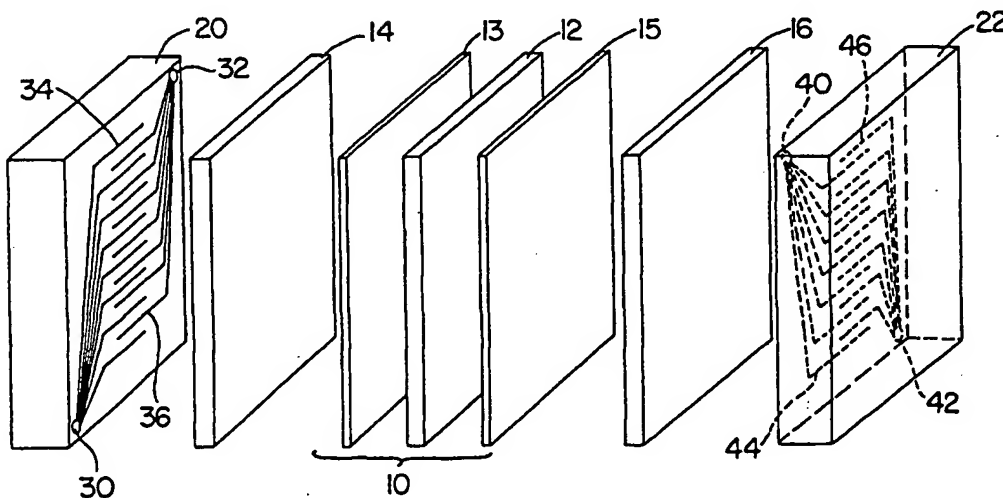
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Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.*

(54) Title: SELF-HUMIDIFYING FUEL CELL



(57) Abstract

A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly has an ion-exchange membrane (12) interposed between hydrogen and oxygen diffusion layers (14, 16) to form a membrane electrode assembly (MEA) (10). The MEA (10) is in turn interposed between a pair of current collector plates (20, 22) having flow field channels (34, 36) for flowing the reactants adjacent the respective diffusion layers to produce corresponding anodic and cathodic electrochemical reactions. Various embodiments of the assembly incorporate one or more of the following features: interdigitated flow field channels (34, 36), countercurrent reactant flows, opposing channel alignment, and uncatalyzed membrane hydration enhancement zones (82, 84).

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Summary of the Invention

It is an object of this invention to provide a polymer electrolyte membrane (PEM) fuel cell capable of maintaining membrane hydration upon the introduction of at least one dry reactant stream into the cell.

It is another object of this invention to provide a PEM fuel cell in which membrane hydration is maintained using water provided as a byproduct of electrochemical reactions within the fuel cell.

It is a further object of this invention to provide a PEM fuel cell which does not require components dedicated to pre-humidification of reactant gas streams.

These and other objects of the invention are achieved by the PEM fuel cell assembly of the present invention. A self-humidifying polymer electrolyte membrane (PEM) fuel cell has a membrane electrode assembly (MEA), comprising an ion-exchange membrane interposed between catalyzed anode and cathode electrodes. The MEA is interposed between a pair of gas diffusion backings, and the resulting structure is interposed between fuel and oxidant flow field plates. The fuel flow field plate has a fuel stream inlet, a fuel stream outlet, and means for flowing the fuel stream therebetween. The oxidant flow field plate has an oxidant stream inlet, an oxidant stream outlet, and means for flowing the oxidant stream therebetween.

In the preferred embodiment of the invention, fuel and oxidant flows are strategically directed to enhance the transfer of water byproduct, through the ion exchange membrane, between opposing gas streams. Dry fuel and oxidant streams are introduced into respective fuel and oxidant inlets. The corresponding flow field plate channels are oriented such that dry portions of reactant stream adjacent to one surface of the membrane generally oppose hydrated portions of reactant stream on the opposite surface of the membrane. In this embodiment, membrane hydration is maximized by providing countercurrent reactant flows. In other words, the reactant gases are directed in generally opposing directions through the fuel cell. Preferably, opposing channel lengths having disparate humidification levels are aligned to provide an increased humidification gradient therebetween, resulting in enhanced mass transfer of water across the membrane in the direction of the less humidified reactant stream. Channel alignment also minimizes the

Brief Description of the Drawings

Fig. 1 is an exploded view of a PEM fuel cell assembly in accordance with the present invention;

5 Fig. 2 is a cross-sectional view of a PEM fuel cell assembly having interdigitated flow field channels in accordance with a preferred embodiment of the present invention;

Fig. 3 is a front view of a field flow plate having an interdigitated reactant flow channel design in accordance with a preferred embodiment of the present invention;

10 Fig. 4 is a schematic of a preferred fuel cell assembly in which opposing collector plate channels are shown superimposed on one another;

Fig. 5 is a schematic of a fuel cell assembly having membrane hydration enhancement zones in accordance with an alternate embodiment of the present invention;

Fig. 6 is a schematic of a fuel cell assembly having membrane hydration enhancement zones in accordance with a further embodiment of the present invention;

15 Fig. 7 is a schematic of a fuel cell assembly incorporating double-interdigitated flow field channels, in which opposing collector plate channels are shown superimposed on one another, in accordance with an alternate embodiment of the invention;

20 Fig. 8 is a graph illustrating the effect of air flow rate and humidification level on the performance of a fuel cell assembly constructed in accordance with the present invention;

Fig. 9 is a graph illustrating the effect of humidification level on the performance of a fuel cell assembly constructed in accordance with the present invention.

interdigitated flow channels on the cathode (oxidant) side operate in a similar manner. As a result of the enhanced electrochemical reactions, the production rate of water byproduct at the cathode is increased. A portion of the additional water produced at the cathode back-diffuses through the membrane toward the anode. Consequently, the availability of water at the anode is also increased when interdigitated channels are used.

Referring briefly to FIG. 3, a front view of flow field plate 20 is depicted to illustrate a unique interdigitated flow field pattern in accordance with the preferred embodiment of the present invention. Conventional interdigitated designs typically employ a plurality of flow channels branching off from a main flow channel, e.g., see U.S. Pat. No. 5,641,586 to Wilson. In contrast, the present invention employs non-overlapping flow channels 34, 36 each extending from a reactant stream port 30, 32. The interdigitated flow pattern of the present invention results in more uniform fluid flow distribution, reduced channel moisture retention, and decreased channel pressure drop. Consequently, more uniform electrical current density is achieved across the fuel cell.

Referring now to FIG. 4, the fuel and oxidant flow field plate channels are shown superimposed for the purpose of discussion. In the preferred embodiment of the present invention, the fuel and oxidant flow fields are oriented to achieve countercurrent fuel and oxidant flow streams. In other words, the fuel and oxidant streams flow in generally opposed directions across the fuel cell assembly. The water content of both the fuel and oxidant streams increases in the flow direction of the respective reactant through the fuel cell. Therefore, by employing a countercurrent flow arrangement, the region of the anode layer with the highest water content substantially coincides with the region of the cathode layer having the lowest water content, and vice versa. As a result, countercurrent reactant flow streams result in more uniform hydration of the ion-exchange membrane.

Fuel and oxidant inlet ports are denoted by reference numerals 30 and 42, respectively. Fuel and oxidant outlet ports are denoted by reference numerals 32 and 40, respectively. The horizontal lengths of the corresponding fuel and oxidant channels are shown slightly offset from one another in a vertical direction for illustrative purposes; although such an arrangement is possible, it is not preferred. Preferably, the horizontal lengths of fuel inlet channels 34 and oxidant outlet channels 44, and the horizontal lengths of oxidant inlet channels 46 and fuel outlet channels 36, overlie one another when viewed

membrane. This results in both local membrane hydration and increased humidification of the reactant stream flowing on the opposite side of the membrane. Lateral absorption of water through the membrane results in increased hydration of catalyzed regions of the membrane as well.

5 Membrane hydration is further enhanced by the lack of electrochemical reactions in these hydration enhancement zones. As previously described, the fuel cell electrochemical reactions at the respective electrodes are initiated by catalyst layers at the membrane/diffusion layer interfaces. The heat produced by these electrochemical reactions tends to dry the membrane locally. However, absent a catalyst, the gas reactants flow
10 without producing these exothermic electrochemical reactions. The reduced membrane temperatures decrease local membrane dehydration.

 Preferably, uncatalyzed areas 82 and 84 are strategically located proximate to reactant flow inlet and outlet areas on opposite sides of catalyzed area 80. Since reactant humidification typically increases in the reactant flow direction, the lowest reactant
15 humidification levels typically occur near the reactant channel inlets, and the highest reactant humidification levels typically occur near the reactant channel outlets. At least a portion of the humidified outlet channel lengths are routed through the humidification zones 82, 84, hydrating the membrane locally through absorption of reactant stream water. Inlet channels carrying dry reactant gas are routed through the humidification zones 82, 84 on
20 the opposite side of the membrane. The humidification gradient across the membrane, caused by the opposing dry and humidified reactant streams, results in the transfer of water absorbed by the membrane to the respective dry inlet gas streams.

 Humidification zones may be created by utilizing an ion-exchange membrane with integrally attached electrodes that maintain uncatalyzed regions. Alternatively,
25 humidification zones may be created by providing a diffusion layer having both catalyzed and uncatalyzed areas. In some instances, it may be desirable to further treat the diffusion layer such that the catalyzed areas are hydrophobic, and the uncatalyzed areas, corresponding to humidification zones, are hydrophilic. This is easily accomplished by selectively coating the diffusion layer with a hydrophobic material such as Teflon®.
30 Alternatively, humidification zones can comprise an ion-exchange membrane directly interposed between opposing flow field plates, where one or both sides of the membrane

convection, from inlet channels 52, through intermediate channels 54, to outlet channels 56. As a result of the double convection, both reactant and water vapor are more evenly distributed during transport across the polymer electrolyte membrane. This embodiment may further incorporate features of previously described embodiments, e.g., countercurrent reactant flow, superposed channels, etc.

While the preferred embodiments of the invention have been illustrated and described, it will be clear that the invention is not so limited. Numerous modifications, changes, variations, substitutions and equivalents will occur to those skilled in the art without departing from the spirit and scope of the present invention as described in the claims.

flowing an oxidant stream both comprise interdigitated inlet and outlet flow field channels, said oxidant inlet channels and fuel outlet channels, and said oxidant outlet channels and fuel inlet channels, at least partially superposed across said ion-exchange membrane to enhance channel-to-channel water transfer across said membrane.

5

6. A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly as recited in claim 1, further comprising at least one membrane hydration enhancement zone.

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7. A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly as recited in claim 6, wherein said at least one membrane hydration enhancement zone comprises an uncatalyzed area of said membrane interposed between gas diffusion layers.

15

8. A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly as recited in claim 7, wherein at least one of said gas diffusion layers is hydrophilic.

20

9. A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly as recited in claim 6, wherein at least one surface of said membrane is directly adjacent to a flow field plate surface.

25

10. A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly as recited in claim 6, wherein said at least one membrane hydration enhancement zone comprises a plurality of membrane hydration zones dispersed throughout said fuel cell assembly.

11. A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly as recited in claim 6, wherein said at least one membrane hydration enhancement zone comprises deionized water and gas reactant streams directed over opposite sides of said ion-exchange membrane.

18. A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly as recited in claim 16, wherein said fuel and oxidant reactants flows have countercurrent flow directions through said membrane hydration enhancement zone.

5 19. A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly as recited in claim 14, wherein at least one of said means for flowing reactant comprises interdigitated flow field channels.

10 20. A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly as recited in claim 14, wherein at least one of said means for flowing reactant comprises double-interdigitated flow field channels.

21. A method for maintaining membrane hydration in a polymer electrolyte membrane (PEM) fuel cell, the fuel cell having a membrane electrode assembly (MEA) interposed between gas diffusion layers, the gas diffusion layers interposed between fuel and oxidant flow field plates, the method comprising the steps of:

15 introducing fuel and oxidant reactants into said fuel cell through respective fuel and oxidant inlets, at least one of said reactants introduced in a dry, nonhumidified state;

communicating said fuel and oxidant reactants through respective fuel and oxidant

20 flow field channels; and

exhausting said reactants through fuel and oxidant outlets.

22. A method as recited in claim 21, further comprising, prior to the step of exhausting, the step of directing at least one of said reactants through a membrane

25 hydration enhancement zone.

23. A method as recited in claim 21, wherein said reactants are communicated in countercurrent directions through said fuel and oxidant flow field channels.

30 24. A method as recited in claim 22, wherein said reactants are communicated in countercurrent directions through said fuel and oxidant flow field channels.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/21411

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01M 8/04, 2/00

US CL :429/13, 30, 34, 38, 39, 40, 46

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/13, 30, 34, 38, 39, 40, 46

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

search terms: flow field plate, flow plate, countercurrent, interdigitated, humidify, hydrate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,300,370 A (WASHINGTON et al.) 5 April 1994, col. 3, lines 16-60; col. 8, lines 50-67; col. 12, line 67 to col. 13, line 41; Figs. 1, 2, 5, 9.	14, 16, 17, 19-22, 25, 26, 28, 29
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Y		1-13, 15, 18, 23, 24, 27
Y	US 5,773,160 A (WILKINSON et al.) 30 June 1998, col. 2, lines 39-58; col. 4, line 52 to col. 5, line 14; col. 6, lines 56-67; Figs. 9, 10.	1, 3, 4, 5, 12, 17, 18, 23, 24
Y	US 5,472,799 A (WATANABE) 5 December 1995, col. 4, lines 44-49, Figs. 2, 3.	7, 10, 15
Y	US 5,108,849 A (WATKINS et al.) 28 April 1992, col. 4, lines 11-18, Fig. 1.	9

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
B earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*A* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

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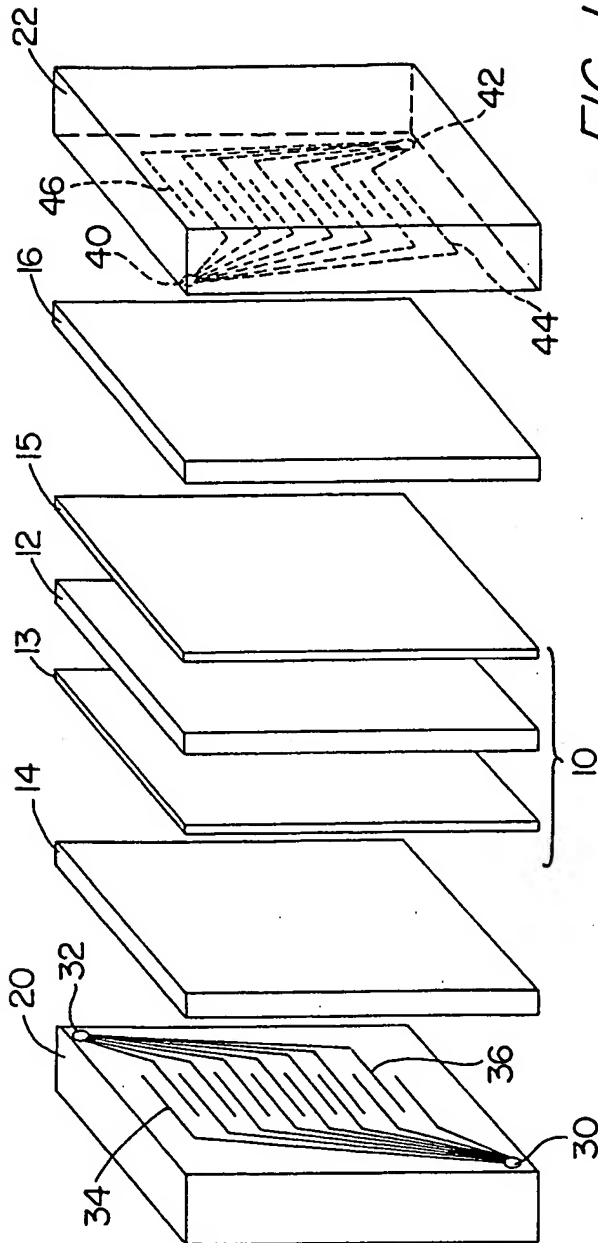


FIG. 1

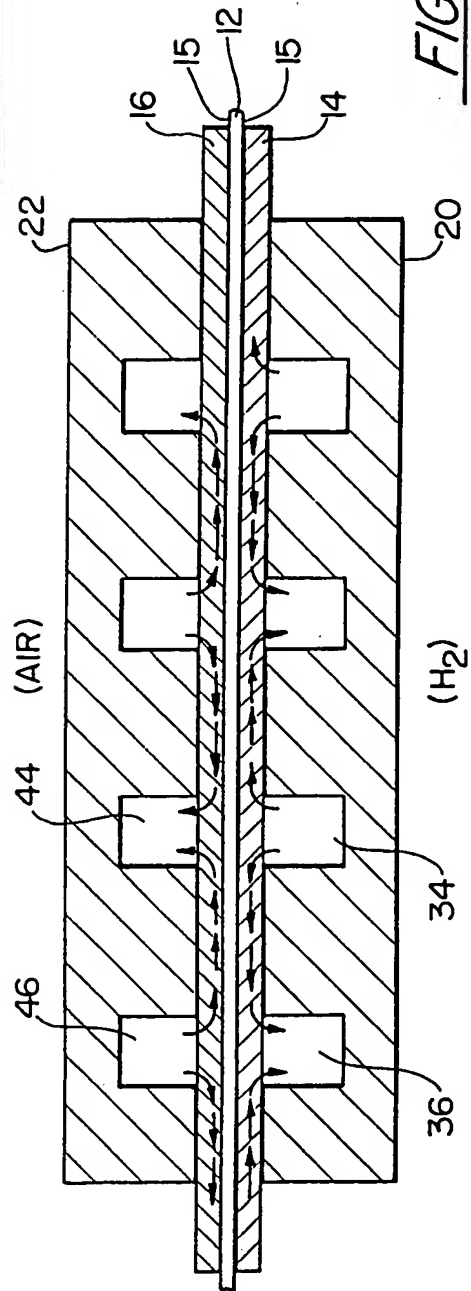
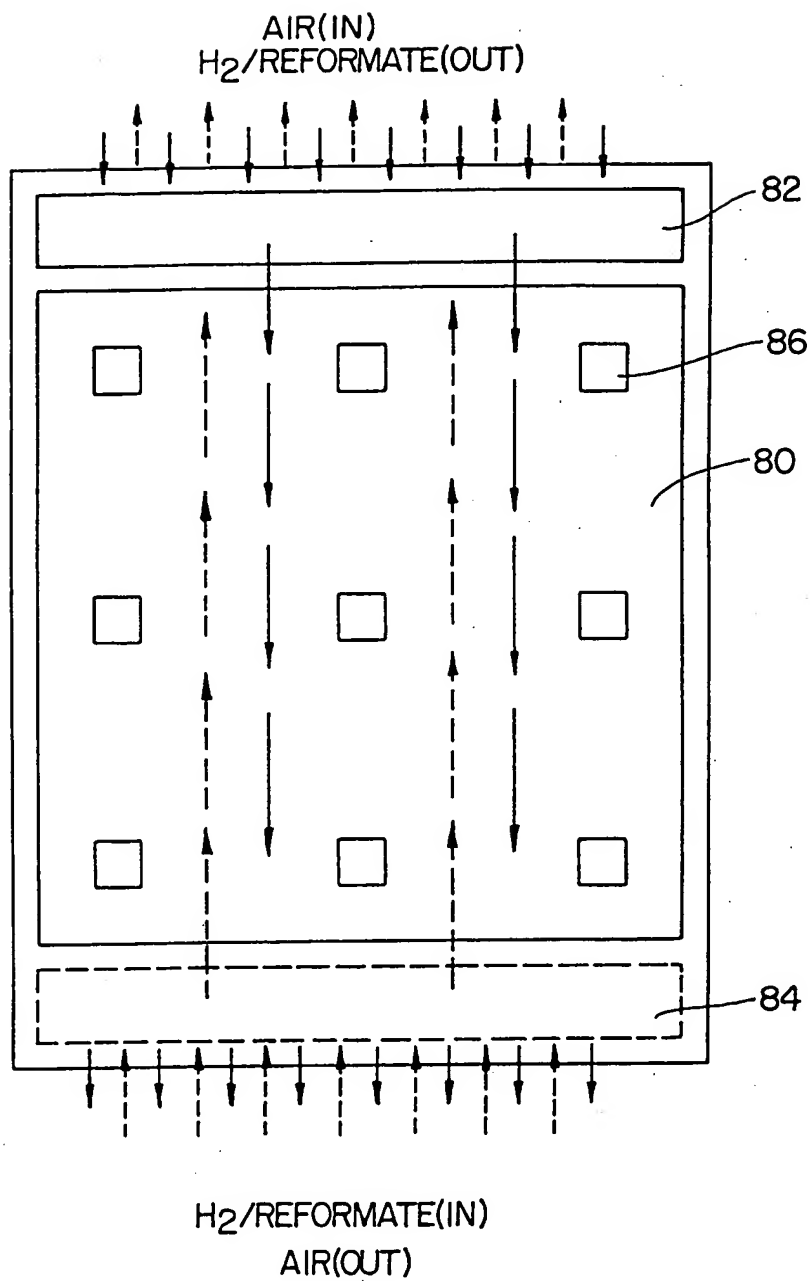


FIG. 2

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FIG. 5

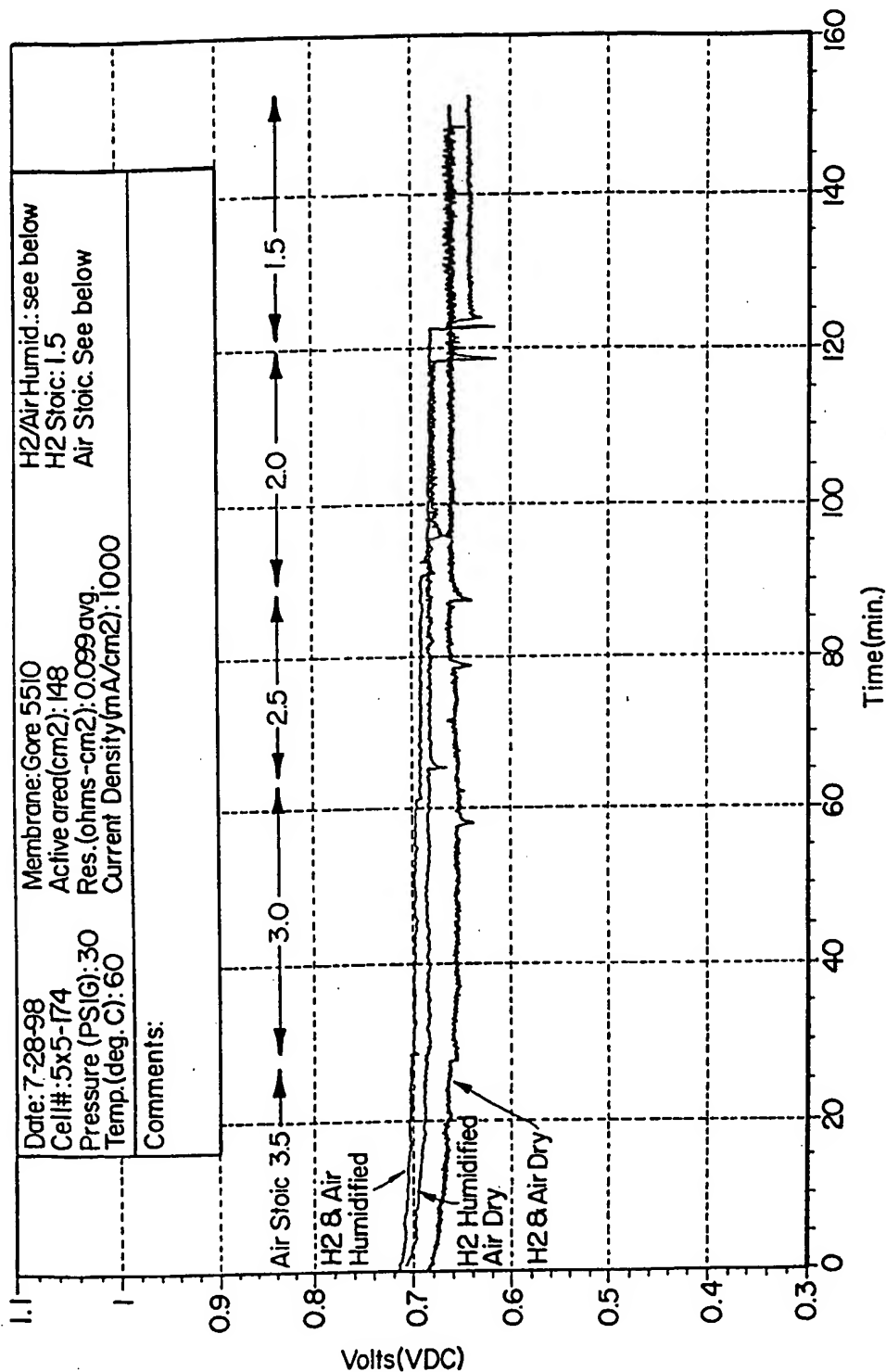


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/21411

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, P	US 5,952,119 A (WILSON) 14 September 1999, col. 3, lines 1-10.	8
A	US 5,641,586 A (WILSON) 24 June 1997, col. 3, line 58 to col. 4, line 7, Fig. 2.	2, 19, 20